ST12 Steam Enhanced Extraction: Has criteria for termination of Steam Injection Been Met?

Status as of 11/6/15 Weekly Progress Report

I. Criteria for amount of steam to be injected:

Final RD/RAWP (May 2014): Table 4-2: SEE to EBR Transition Criteria

Steam injection (guideline)	319,357,000 lbs	Numerical thermal modeling of TTZs.	A targeted total of 319,357,000 lbs of steam is expected to be injected into the TTZ over the course of operations. This represents an average flushing of the TTZ pore volume of 1.6 pore volumes of steam as water throughout operation. Actual steam required to achieve the other criteria may be more or less than this estimate. Because this parameter does not directly measure remediation performance its primary use will be as a guideline to measure progress compared to the design.

Table 5-2 SEE to EBR Transition Criteria Monitoring

Parameter	Target Criteria	Summary of Monitoring or Sampling and Analysis for Evaluation of Progress Toward Transition Criteria
Steam injection (guideline)	319,357,000 lbs	Steam production will be measured at the boilers.

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Total Steam Injected	248.4	million pounds (lbs)
Projected Total Steam Injection	320	million lbs
Steam Injected Vs Projected	78	%

Analysis: Criteria for amount of steam injection has not been met. The design steam injection rate was based on 1.6 pore volumes of steam injection, which is lower than the commonly used criteria of 2 pore volumes of steam. The projected steam injection should be seen as a minimum amount of steam to be injected.

II. Criteria for residual benzene concentrations:

Final RD/RAWP (May 2014): Table 4-2: SEE to EBR Transition Criteria

Benzene concentrations:	100 to 500 µg/L	Concentration range where natural attenuation can complete degradation within the remedy time frame.	Benzene concentrations in extracted groundwater provide an indication of the amount of benzene remaining in the TTZ. These concentrations will be monitored against a target benzene concentration in the 100 to 500 µg/L range within the TTZ. This concentration range is predicted to achieve cleanup levels within the 20-year remedial timeframe based on modelling of groundwater contaminant attenuation outside the TTZs after active EBR (Appendix E). Benzene located around the perimeter of the TTZ and the perimeter/interior extraction wells will be evaluated for benzene concentrations to identify any perimeter influx that may mask benzene removal within the TTZ. It is expected that lower benzene concentrations within this range will be achieved in the interior of the TTZs than at the perimeter.

Table 5-2 SEE to EBR Transition Criteria Monitoring:

Benzene concentrations	100 to 500 µg/L	Benzene concentrations will be monitored in SEE wells during baseline sampling. Samples of extracted water (see Table 5-1) will be used to evaluate benzene concentrations during SEE operation. Sampling locations during operation will be determined in the field with a sampling strategy that starts at influent to the liquid treatment system and then moves progressively out to individual manifolds and, in some cases individual wells to trace the source of benzene contribution. The locations will also be selected to evaluate the relative contribution of contamination from outside vs. inside the TTZs.

Analysis: EPA considers 100 µg/l of benzene in groundwater an appropriate target for a successful remediation, and would not support terminating steam treatment before the stated target (100 – 500 µg/l) is reached

Weekly progress report 11/6/15: LSZ

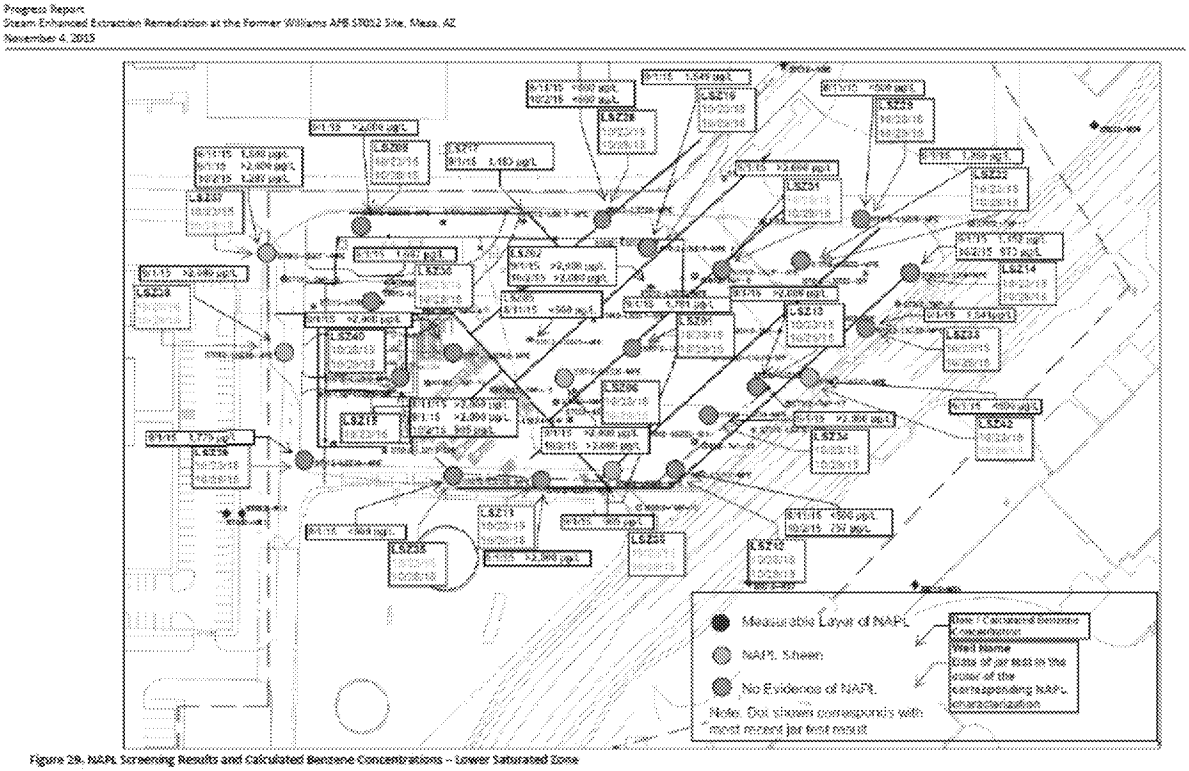

Figure 29. NAPL Screening Results and Calculated Benzene Concentrations – Lower Saturated Zone

Benzene Concentrations in LSZ Exceed 500 µg/L; Criteria has not been met for LSZ

Weekly progress report 11/6/15: UWBZ

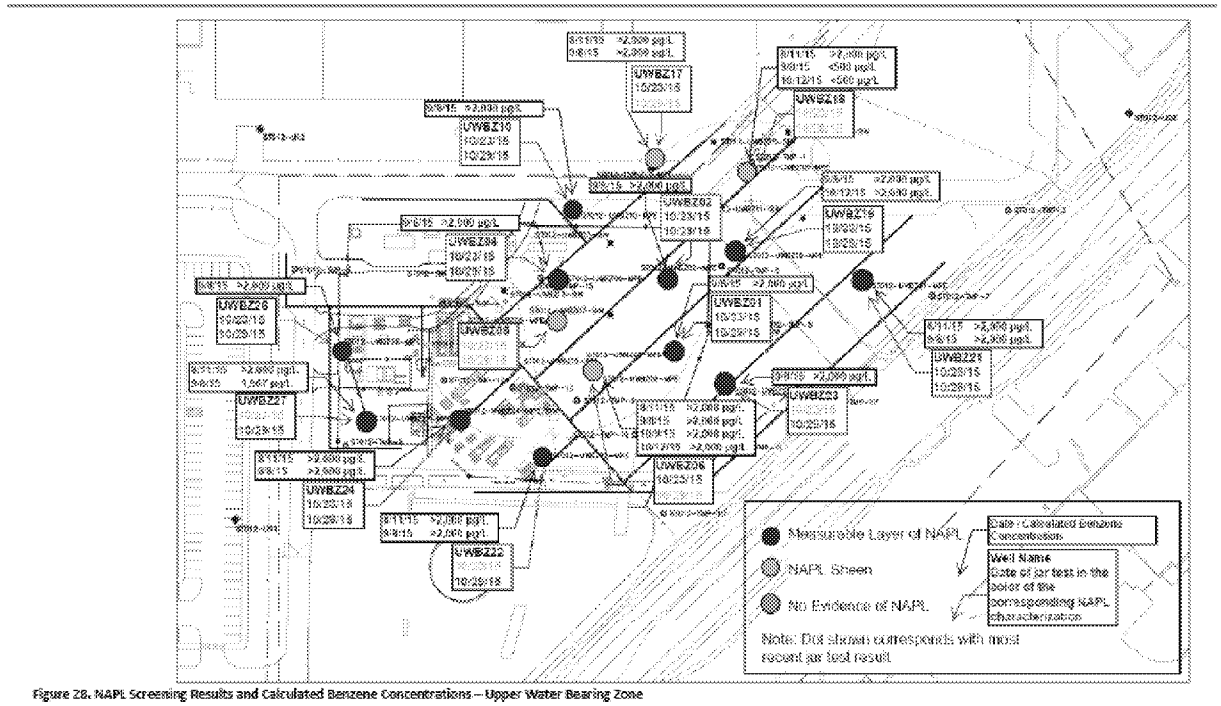

Figure 28. NAPL Screening Results and Calculated Benzene Concentrations – Upper Water Bearing Zone

Benzene Concentrations in UWBZ exceed 500 µg/L; significant NAPL present, Criteria has not been met for UWBZ

Weekly progress report 11/6/15: CZ

22. NAPL Screening Results and Calculated Benzene Concentrations

Figures 27-29 below present the screening level results for NAPL detected in samples collected from MPE wells across the site. Screening samples are typically collected on a weekly basis. The figures below also include calculated benzene concentrations of groundwater samples collected from MPE wells across the site.

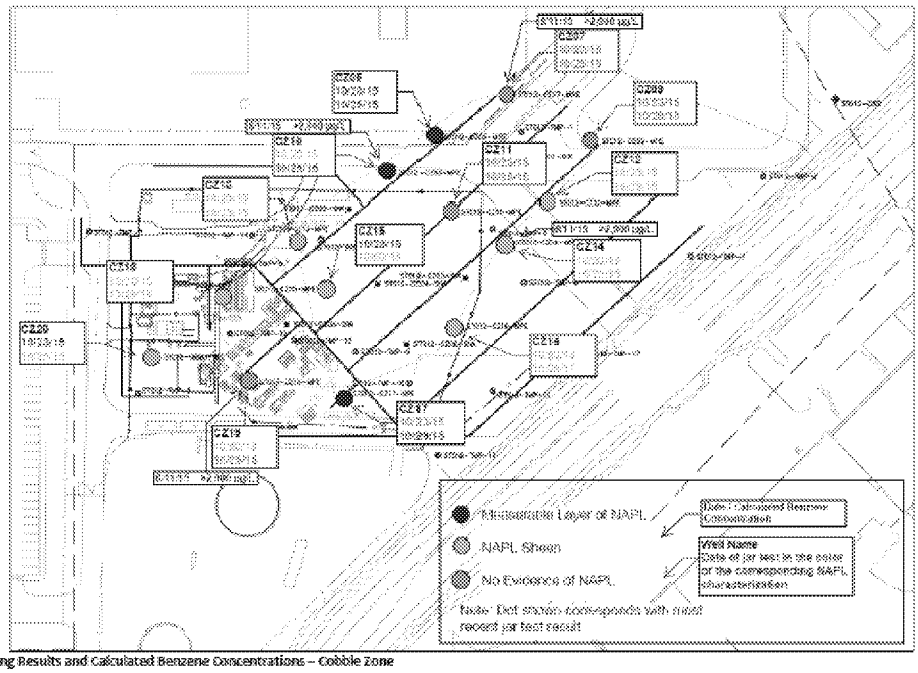

Figure 27. NAPL Screening Results and Calculated Benzene Concentrations – Cobble Zone

Benzene concentrations Exceed 500 µg/L in CZ, NAPL present; Criteria has not been met for CZ

III. Criteria for Mass Removal

Final RD/RAWP (May 2014): Table 4-2: SEE to EBR Transition Criteria

Table 5-2 SEE to EBR Transition Criteria Monitoring:

Mass removal	Less than 10 percent of peak removal rate	Mass removal will be determined from a sum of individual mass removal rates such as: • Recovered LNAPL as measured by totalizing flow meter on the inlet to the LNAPL storage tanks • Mass in extracted vapors as measured at vapor collection manifold (vapor flow rate logged in PLC and influent vapor measured by FID/PID) • Mass in extracted water as measured in air stripper off gas and liquid laboratory samples (liquid discharge flow rate logged in the PLC, air stripper blower flow rate logged in the PLC, air stripper off gas measured by FID/PID, water treatment influent and GAC influent)

Final RD/RAWP (May 2014): Table 4-2: SEE to EBR Transition Criteria

Mass removal	Less than 10 percent of peak removal rate	10 percent selected as an indication of significant decline in mass removal by SEE. This target is consistent with removal rate trends observed at other sites and provides some accommodation for the uncertain mass present and the uncertain peak extraction rate. The actual site-specific removal rate curve will be evaluated to comm or adjust the appropriateness of this value to represent a condition of diminishing returns.	The rate of contaminant mass removal from the subsurface will play a major factor in determining when SEE is complete or sufficient. The mass removal rate will be closely monitored and will be optimized by using pressure cycling events. Toward the end of the operational period, the mass removal rates will be modest when compared to the peak removal rates (typically less than 10 percent of the rate observed at peak operations). Contaminant mass located around the perimeter of the TTZ may contribute a continuing source of mass for removal by the SEE system, which could mask the progress of mass removal within the TTZs, so the contribution of perimeter/interior extraction wells may be evaluated for mass removal towards the end of operations to identify any perimeter influx. Continued operation below the 10 percent of peak removal rate may be implemented depending on the significance of continued mass removal, the status of COC concentrations (e.g., benzene) in extracted fluids, and the need/ability for EBR to achieve further degradation based on data collected during the EBR field test.

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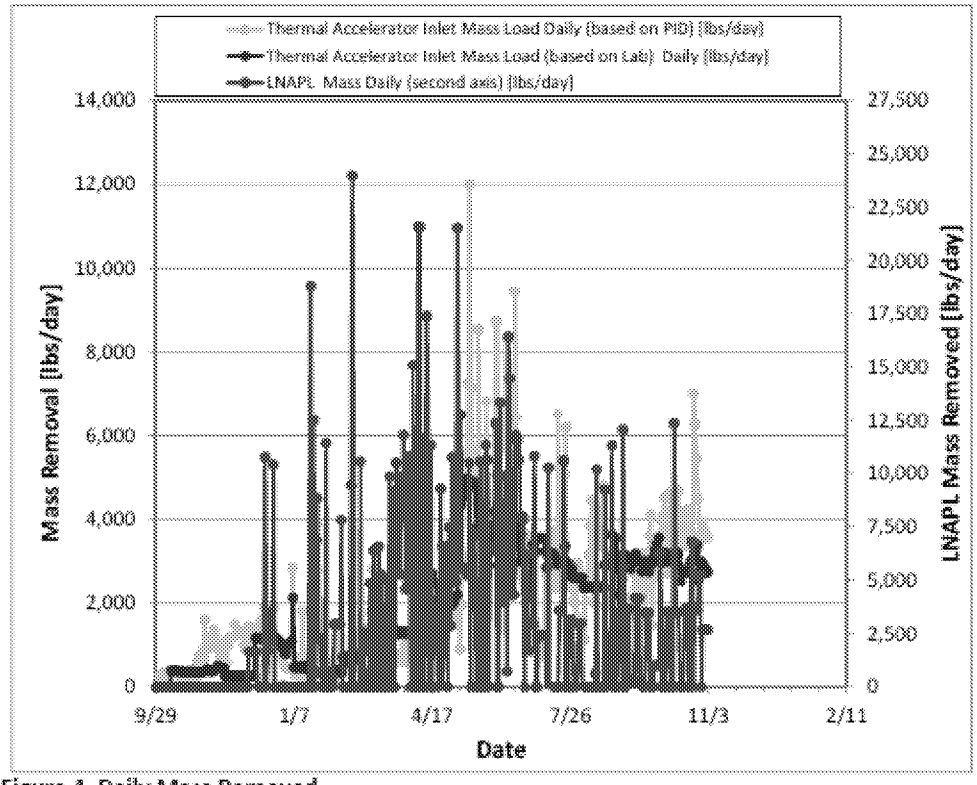

Figure 4. Daily Mass Removed

Analysis: Current LNAPL recovery is at 30% of peak removal rate; vapor recovery is 50% of peak removal rate; Criteria for termination of steam injection has not been met. EPA considers the criteria of 10% of the peak mass recovery to be high compared to the mass recovery rates that have been used to support thermal treatment termination at other sites. We cannot support termination of treatment when thousands of pounds of contaminant mass are being extracted daily.

IV. Criteria for completion of pressure cycling:

Final RD/RAWP (May 2014): Table 4-2: SEE to EBR Transition Criteria

Completion of Pressure Cycling	Completion of multiple pressure cycles in each area	Pressure cycling has been demonstrated at other sites to improve mass removal beyond that achieved by uniform heating only.	Once the TTZ temperatures have stabilized, further mass removal improvement can be achieved by releasing steam pressure to cause volatile LNAPL constituents to rapidly vaporize for subsequent collection by MPE wells. The process of building and releasing the pressure is repeated until no additional significant increases in effluent vapor phase concentrations occur when steam pressure is reduced.

Table 5-2 SEE to EBR Transition Criteria Monitoring:

Completion of Pressure Cycling	Completion of multiple pressure cycles in each area	Because the pressure cycling process results in the volatilization of contaminants upon release of the pressure, extracted vapors will be the primary source for measurement of pressure cycling effectiveness. Vapors will be primarily monitored with hand held devices with the objective to demonstrate diminishing returns from pressure cycles.

Analysis: This criterion is nonspecific. The purpose of pressure cycling, and indicated in the statements above is to enhance volatilization of contaminants. It is not intended to improve mobilization and recovery of NAPL which may have been retarded by premature initiation of pressure cycling. Ideally, the bulk of NAPL should be removed first before initiation of pressure cycling as the finishing step. As long as NAPL is being recovered, steam injection should continue, then institute pressure cycling to remove the last of the volatiles. It is unfortunate that we did not discuss criteria for initiation of pressure cycling in the work plan.

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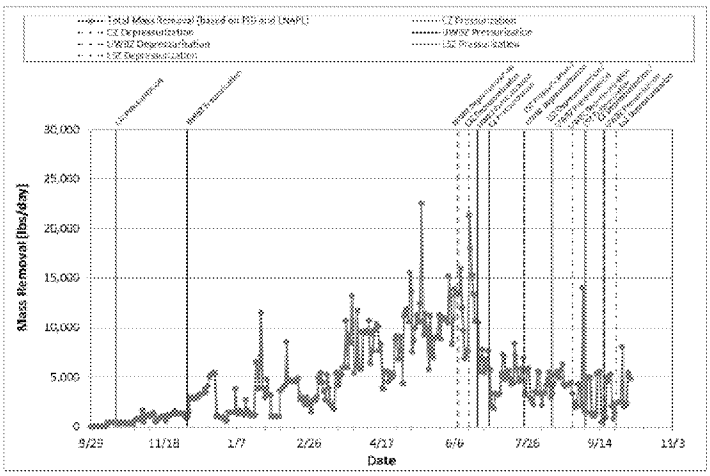
Pressure Cycling and Mass Removal

Mass Removal over Time



- Peak mass removal occurred April – June 2015 (vapor and NAPL phases)

NAPL Recovery was increasing up until the time pressure cycling was imitated. Did decline in recovery rate occur because pressure cycling was initiated early? Consider the analogy of liquid recovery with pressure cycling similar to turning spigot of garden hose on and off….

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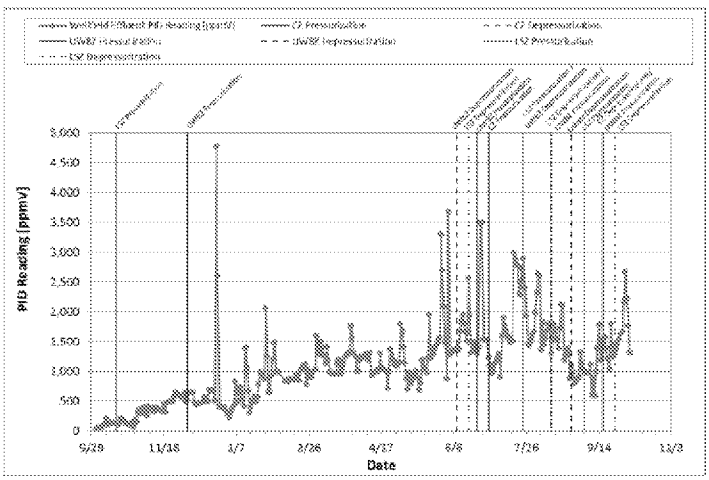
Pressure Cycling and Vapor Mass Removal

Wellfield Vapor Influent PID Concentrations over Time



- Vapor phase removal has increased after initiation of pressure cycling

The criteria in the RD/RAWP stating that "the process is repeated . . .until no additional significant increases in effluent vapor phase concentrations occur when steam pressure is reduced" has not been met.

V. Criteria for Boiling Temperatures

Final RD/RAWP (May 2014): Table 4-2: SEE to EBR Transition Criteria:

Table 4-2 SEE to EBR Transition Criteria

Parameter	Target Criteria	Basis for Target Criteria	Description
Subsurface Temperature	Varies by Depth (higher boiling temperatures with depth – see Figure 5.3, in Appendix D of the RD/RAWP	Numerical thermal modeling of TTZs supported by depth-specific boiling points.	Efforts will be made during operations to inject steam throughout the TTZ to target achievement of boiling point temperatures for groundwater throughout the TTZ. A steam zone will be generated and maintained where possible with the goal of pushing steam across the TTZ to form a steam zone between injection and extraction wells, with breakthrough of steam demonstrated at extraction wells. It is anticipated that a steam zone will not be able to be created and maintained in the LPZ. Other areas of low permeability may also be discovered during operation that limit achievement of target temperatures. Operational adjustments will be made where possible to increase temperatures in such zones that are slower to reach target temperatures. The energy balance will be used to support evaluation of achieving the temperature goal. Shut-down of steam will only be considered after achieving boiling point temperatures throughout the TTZ with the exception of the LPZ and other potential areas of low permeability and provided that operational adjustments are made to attempt to achieve the temperature goal in areas that are resistant.

Table 5-2 SEE to EBR Transition Criteria Monitoring:

Subsurface Temperature	Varies by Depth (higher boiling temperatures with depth – see Figure 5.3, in Appendix D of the RD/RAWP)	17 individual TMPs will be equipped with 15-24 vertical temperature measurement locations per TMP. In addition, each SIW and MPE well will be equipped with the infrastructure for a co-located TMP to be installed for temperature measurements to be collected. Co-located TMPs will be permanently installed for the 18 deep SIWs in the LSZ and will monitor the temperature at the top, middle and bottom of these wells. Two mobile temperature arrays in the CZ and two mobile temperature arrays in the UWBZ will be used to monitor temperatures in the remaining MPEs and SIWs (top, middle and bottom depths). Temperature monitoring of the SIW/MPE wells, along with extracted fluid and vapor temperatures, will supplement the 17 individual TMPs to monitor temperature distribution at the site.

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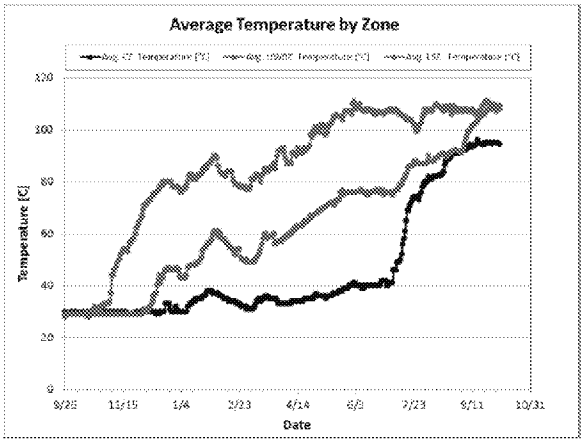
Site ST012 SEE
Average Temperatures by Zone



- Average temperatures continue to increase in CZ and UWBZ
- LSZ temperature sensors 240 ft bgs and lower generally do not show steam temperatures

CZ Target Treatment Temperature: ~100°C
UWBZ Target Treatment Temperature: ~114°C
LSZ Target Treatment Temperature: ~134°C

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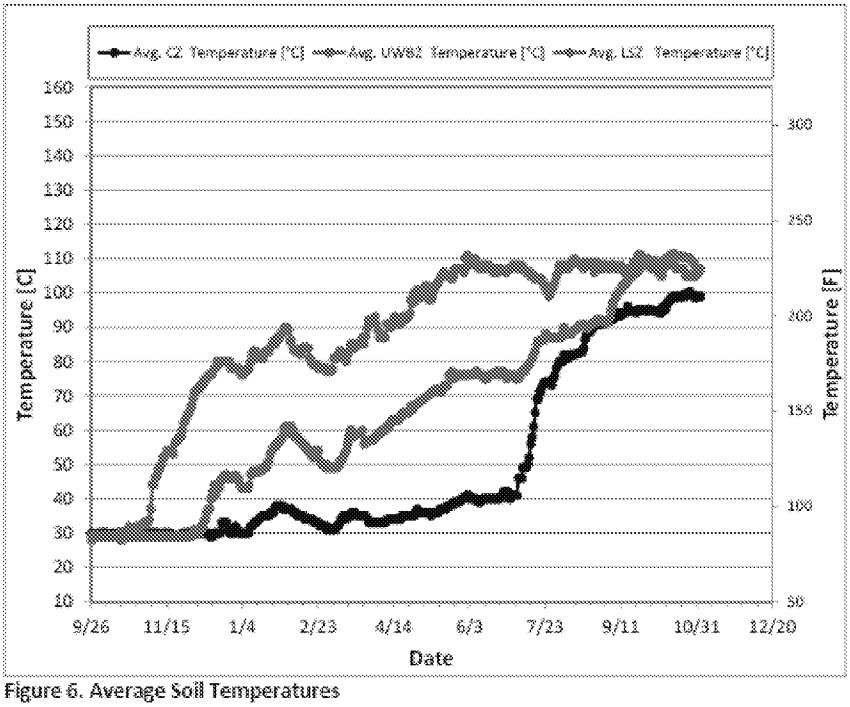

Figure 6. Average Soil Temperatures

Analysis: According to slide 20 from Oct 15, the target temperature for the CZ is ~ 100C, which has almost been met. The target for the UWBZ is ~114C, which has almost been met. The target for the LSZ is ~134C, which has not been met.